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(54) IMPROVEMENTS IN PIEZOELECTRIC TRANSDUCERS

(71) We, MURATA MANUFACTURING CO. LTD., a Japanese Body Corporate, of No. 16 Kaiden Nishijin-cho, Nagaokakyo-shi, Kyoto-fu, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to piezoelectric ultra-sonic transducers.

Ultrasonic transducers are known which utilize one or more piezoelectric elements made of piezoelectric ceramic material. In these piezoelectric ultrasonic transducers known in the art, the piezoelectric elements are conventionally provided with one or more resonating members to increase the amplitude of mechanical vibration when the transducers are used as sound emitters and the electrical output thereof when the transducers are used as microphones. For example, one known piezoelectric transducer comprises a piezoelectric element sandwiched between two metal plates which are used as resonating members. This piezoelectric transducer has low sensitivity and narrow bandwidth and is complex in construction and poor in reliability. Thus, there have been many problems in such prior art transducers awaiting solution.

A known piezoelectric microphone comprises a piezoelectric bimorph and a funnel-like resonating member of metal connected to the piezoelectric bimorph by means of a connecting shaft extending through the central portion of the bimorph. The use of the funnel-like appendant resonating member makes it possible to improve the sensitivity and bandwidth of the transducer to some extent. However, in mass production of such transducers, it is difficult to obtain desired electrical characteristics since these are greatly affected by the length of the connecting shaft and the shape of the appendant resonating member. Moreover, delicate care has to be exercised to prevent the resonating member from becoming deformed since it is made of a thin metal with a thickness of about 0.1 mm which tends to deform by mechanical shock. Also, it can take a long time to adjust the centre frequency of the transducer to the predetermined value since a large change in the frequency characteristic thereof results from a small change in the length of the connecting shaft. In addition, the piezoelectric bimorph used in such a transducer is difficult to manufacture since it is required to have an aperture for attachment of the connecting shaft at the central portion thereof.

According to the present invention, there is provided a piezoelectric transducer for transmitting or receiving ultrasonic waves comprising a base plate provided with a cylindrical supporting frame, on the central region of one of its surfaces, a piezoelectric bimorph attached at one of its surfaces to the supporting frame by an elastic organic binder, said supporting frame being so designed as to have a diameter equal to the diameter of a nodal circle developed at a predetermined resonant frequency of the transducer, a frustum-shaped appendant resonating member made of synthetic resin and attached at its small base to the central region of the other surface of the piezoelectric bimorph, and a casing fixed to the base plate for housing said piezoelectric bimorph.

The resonating member may be moulded from a synthetic resin selected from the group consisting of ABS resins and polycarbonate resins.

The resonating member may be provided with a recess at the centre portion thereof on the side of the small base thereof; alternatively the resonating member may be provided with an aperture passing through the axis thereof.

Preferably the resonating member is in the form of a frustum of a cone.

Specific embodiments of piezoelectric transducers will now be described by way of example with reference to the accompanying drawing, in which:

Figure 1 is a cross sectional view of a basic form of piezoelectric ultrasonic transducer embodying the present invention;

Figure 2 is an exploded perspective view of the transducer shown in Figure 1;

Figure 3 is a graph showing the frequency characteristic of the transducer of Figure 1;

Figure 4 is a perspective view showing two frustum-like resonating members capable of being used in the present invention;

Figure 5 is a cross sectional view of another form of piezoelectric ultrasonic transducer embodying the present invention with the casing removed; and

Figure 6 is a cross sectional view of still another form of piezoelectric ultrasonic transducer embodying the present invention with the casing removed.

Referring to Figures 1 and 2, there is shown a basic form of a piezoelectric transducer for transmitting or receiving ultrasonic waves, made in accordance with the present invention, which comprises a base plate 1 made of synthetic resin or other insulating material and provided with a cylindrical supporting frame 2 on one surface thereof to form a centre recess 3. As shown, frame 2 is separate from but attached to the base plate 1; alternatively the supporting frame 2 may be moulded integrally with the base plate 1. The supporting frame 2 is so designed as to have a diameter equal to the diameter of a nodal circle developed at a predetermined resonant frequency of the transducer. The diameter of the nodal circle developed at the predetermined resonant frequency may be obtained in the following manner.

As is known, the relationships between the resonant frequency (ω_m) and the radius (r) of the piezoelectric bimorph is given by the following equation:

$$\omega_m = \frac{\alpha_m^2}{\sqrt{12}} \cdot \frac{t}{r^2} \cdot \sqrt{\frac{E}{\rho(1-\sigma^2)}}$$

where

α_m = constant
t = thickness
E = Young's modulus
ρ = density of the piezoelectric ceramic
σ = Poisson's ratio

If the piezoelectric bimorph is square-shaped, the radius (r) in the above equation may be replaced by

$$\left(\frac{L}{2}\right).$$

The symbol L is a length of a diagonal line of the ceramic bimorph.

The relationship between the radius or the length of diagonal line and the diameter (D) of the nodal circle may be represented by the following experimental equation.

When the bimorph is disk-shaped:

$$D = 1.1032r$$

When the bimorph is square shaped:

$$D = 0.5516L$$

Accordingly, if the resonant frequency is determined, the size of the piezoelectric bimorph is determined, whereby the diameter of the nodal circle developed at the resonant frequency can be obtained.

A shield plate 4 of metal is attached to the other surface of the base plate 1 by means of electrode terminals 5 passing through the base plate 1 and the shield plate 4. One of the electrode terminals 5 is electrically connected with the shield plate 4, and the other terminal 5 is insulated from the shield plate 4. A square-shaped piezoelectric bimorph 6 is attached to and supported on the supporting frame 2 at the central region of its one surface by an elastic organic binder. The bimorph 6 comprises a pair of piezoelectric ceramic plates joined together in face-to-face relationship and polarized in opposed directions with respect to each other. Lead wires 7 attached to the opposed electrodes of the bimorph 6 are connected electrically to the electrode terminals 5. A frustum-shaped resonating member 8 made of synthetic resin is attached at its small base 8*a* to the central region of the other surface of the bimorph 6 by an elastic organic binder. An open-ended cylindrical protective casing 9 is securely fixed to the circumference of the base plate 1 at one of its open end portions. The casing 9 is provided with an annular flange 9*a* at its other open end portion and covered with a screen 10 thereacross.

Figure 3 illustrates the frequency characteristic of the piezoelectric ultrasonic transducer mentioned above. As will be seen from this Figure, the transducer comprising a frustum-shaped appendant resonating member made of synthetic resin has an effective frequency bandwidth from 37 kHz to 44 kHz and sensitivity of 60 dB at the centre frequency of 40 kHz.

In the above embodiment, the appendant resonating member 8 is employed in the form of a frustum of a cone, but various frustum-shaped resonating members other than that may alternatively be employed. Two possible shapes are shown in Figure 4. In Figure 4 (a) and (b), resonating members 8 are in the form of a frustum of a square pyramid and a hexagonal pyramid, respectively. Of the described resonating members, a resonating

member in the form of a frustum of a cone is the most preferred.

Referring to Figure 5, there is shown a modified form of part of the piezoelectric ultrasonic transducer shown in Figure 1. In this embodiment, a resonating member in the form of a frustum of a cone is provided with a recess at the centre portion on the side of its small base which is attached to the piezoelectric bimorph.

Referring to Figure 5, a piezoelectric ultrasonic transducer comprises a base plate 1, a cylindrical supporting frame 2 formed on the upper surface of the base plate 1 integrally therewith, a pair of electrode terminals 5 extending through the base plate 1, a disc-like piezoelectric bimorph 6 mounted on the supporting frame 2 at the central region of one of its surfaces, an appendant resonating member 11 made of synthetic resin provided with a recess 12 and mounted on the central region of the other surface of the bimorph 6, and a cylindrical casing (not shown) for housing the assembly. The provision of a recess at the central portion of the resonating member on the side of its small base prevents deviation of the centre frequency of the transducer from the predetermined value and improves the sensitivity of the transducer since the small base surrounding the recess is positioned to surround the centre of the bimorph where the amplitude is largest.

Referring to Figure 6, there is shown another form of the present invention in which an appendant resonating member 13 made of synthetic resin in the form of a frustum of a cone is provided with an aperture 14 passing through the axis thereof instead of the recess 12 in the embodiment of Figure 5.

The resonating members shown in Figures 4*a* and 4*b* can be provided with a recess as shown in Figure 5, or an aperture as shown in Figure 6.

Since the above described resonating members are formed of synthetic resin they will not easily become deformed even if subjected to mechanical shock during assembly of the transducer as will the aforementioned resonating members formed of thin metal.

The abovedescribed piezoelectric transducers are suitable for transmitting and receiving ultrasonic waves in air, and have higher sensitivity, wider frequency bandwidth and higher reliability as compared with the abovementioned transducers known in the art. Such a piezoelectric ultrasonic transducer is suitable for use in a remote control device for a television set. Further, it is also possible to prevent the transducer from deviation of the centre frequency thereof from the predetermined value, and this results in a smaller production spread of the electrical characteristics of mass produced transducers. In addition, the piezoelectric transducer of the present invention is simple in construction so that it is easy to manufacture.

WHAT WE CLAIM IS:—

1. A piezoelectric transducer for transmitting or receiving ultrasonic waves comprising a base plate provided with a cylindrical supporting frame on the central region of one of its surfaces, a piezoelectric bimorph attached at one of its surfaces to the supporting frame by an elastic organic binder, said supporting frame being so designed as to have a diameter equal to the diameter of a nodal circle developed at a predetermined resonant frequency of the transducer, a frustum-shaped appendant resonating member made of synthetic resin and attached at its small base to the central region of the other surface of the piezoelectric bimorph, and a casing fixed to the base plate for housing said piezoelectric bimorph.

2. A piezoelectric transducer as claimed in claim 1, wherein the frustum-shaped resonating member is made from a synthetic resin selected from the group consisting of ABS resins and polycarbonate resins.

3. A piezoelectric transducer as claimed in either claim 1 or claim 2, wherein the frustum-shaped resonating member is provided with a recess at the centre portion thereof on the side of the small base thereof.

4. A piezoelectric transducer as claimed in either claim 1 or claim 2, wherein the frustum-shaped resonating member is provided with an aperture passing through the axis thereof.

5. A piezoelectric transducer as claimed in any one of the preceding claims, wherein the resonating member is in the form of a frustum of a cone.

6. A piezoelectric transducer substantially as hereinbefore described with reference to Figures 1 to 3, or Figure 5, or Figure 6 of the accompanying drawing.

7. A piezoelectric transducer as claimed in claim 6, when modified in accordance with either of Figures 4*a* and 4*b* of the accomming drawing.

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1 SHEET This drawing is a reproduction of the Original on a reduced scale

Fig. 1.

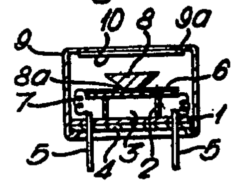

Fig. 2.

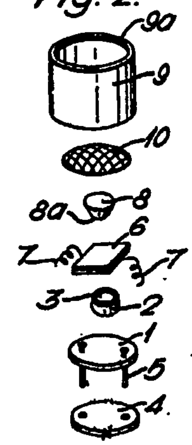

Fig. 3.

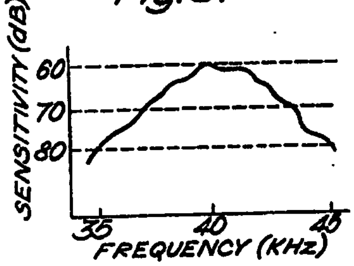

Fig. 4.

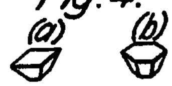

Fig. 5.

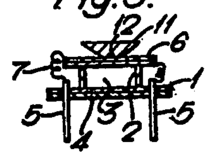

Fig. 6.